On-Farm Assessment of Soil Quality in California's Central Valley

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ABSTRACT

The high-value, large-scale crop production systems in the San Joaquin Valley (SJV) of California typically entail intensive tillage and large fertilizer and water inputs but few C additions to the soil. Such practices often contribute to a decline in soil quality. Our objective for this participatory study was to examine the effects of supplemental C management practices (SCMPs) on various soil quality indicators. To increase farmer participation, we conducted the study on farms using a variety of SCMPs, including cover crops, compost and manure amendments, and several different crop rotations common to the region. The SCMPs significantly changed a number of soil properties, including soil organic matter (SOM); total Kjeldahl N; microbial biomass C and N; exchangeable K; Olsen P; and extractable Fe, Mn, and Zn. A comparison including previously established, adjacent organic, conventional, and transitional fields in addition to the treatment fields at one farm revealed significant differences in 16 of 18 soil quality indicators. A soil quality index computed for this farm scored the established organic system significantly higher than the conventional system. Our results suggest that significant changes in several soil quality indicators occur with a variety of SCMPs. This is especially noteworthy considering the intensive tillage, irrigation, and hot, semiarid environment of the SJV, California, where increases in SOM and related soil properties are generally not expected in a 3-yr study.

Western Fresno County in the San Joaquin Valley (SJV) of California is one of the world's most productive agricultural regions. Farmers in this area produce more than one-third of the county's annual $3 billion agricultural output, making it the highest revenue-producing county in the USA (California Dep. of Food and Agric., 1997). Dominant crop rotations include annual crops (Mitchell et al., 1999) such as processing tomato (*Lycopersicon esculentum* L.), cotton (*Gossypium hirsutum* L.), onion (*Allium cepa* L.), garlic (*A. sativum* L.), cantaloupe (*Cucumis melo* L. var. *reticulatus* Naud.), wheat (*Triticum aestivum* L.), sugarbeet (*Beta vulgaris* L.), and lettuce (*Lactuca sativa* L.).

The intense production practices used in this region include frequent and intensive tillage, irrigation, and extensive use of fertilizers and pesticides but few additions of organic amendments to the soil (Mitchell et al., 1999). These intensive practices have raised concerns about resource management and water consumption as well as environmental concerns such as fugitive dust, ground water quality, and food safety (SJV Drainage Program, 1990; Mitchell et al., 1999). Mitchell et al. (1999) also reported a perceived decline in soil quality among producers. As a result of these concerns, many SJV producers have begun to question the long-term sustainability of their intensively managed agricultural systems.

To help farmers in the SJV evaluate the soil quality effects of alternative soil management practices, the West Side On-Farm Demonstration Project (WSD) was conducted from 1995 to 1998. This participatory research and extension program originally included 11 large-scale SJV row-crop producers, University of California Cooperative Extension researchers, USDA Natural Resources Conservation Service (NRCS) conservationists, USDA-ARS scientists, and private-sector consultants.

Developing science-based guidelines to quantify impacts of routinely used organic inputs in this region was identified as an important priority among the project's farmer participants (Mitchell and Goodell, 1996). A brief, written survey of 15 participants, conducted during a routine project meeting, invited input about their interest in an indexing tool to evaluate soil quality (sensu Andrews and Carroll, 2001; Karlen et al., 1998). Fourteen of the respondents indicated that a soil quality assessment tool would be useful to compare management alternatives (one blank response) (S.S. Andrews, J.P. Mitchell, and D.L. Karlen, unpublished data, 1999). Based on that level of participatory support, our project objectives were to (i) facilitate information exchange among farmers, consultants, and researchers regarding these soil management practices; (ii) monitor and evaluate on-farm, side-by-side comparisons of various SCMPs; and (iii) demonstrate the use of a soil quality index (SQI) for the region.

MATERIALS AND METHODS

Site Descriptions

Side-by-side comparisons of conventional and organic-based production systems were established on 11 farms in autumn 1995. The farms were located in the western SJV between Mendota and Huron, CA. At the beginning of the project, we randomly designated adjacent fields at each farm to receive either conventional or alternative treatments. The fields varied in size but generally ranged from 30 to 60 ha

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Published in Agron. J. 94:12–23 (2002).

Abbreviations: BD, bulk density; CEC, cation exchange capacity; EC, electrical conductivity; MBN, microbial biomass nitrogen; MDS, minimum data set; NRCS, Natural Resources Conservation Service; PC, principal component; PCA, principal component analysis; PMN, potentially mineralizable nitrogen; SAFS, Sustainable Agriculture Farming Systems (Project); SAR, sodium adsorption ratio; SCMPs, supplemental carbon management practices; SJV, San Joaquin Valley; SOM, soil organic matter; SQI, soil quality index; TKN, total Kjeldahl nitrogen; WSA, water-stable aggregates; WSD, West Side On-Farm Demonstration Project; x-K, exchangeable potassium.

Table 1. Management treatments and crops grown at six farms participating in West Side On-Farm Demonstration Project (WSD) from 1996 through 1998.

	1996				1997				1998			
	Amendment				Amendment				Amendment			
System	Rate	Type	Syn. fert.†	Crop	Rate	Type	Syn. fert.	Crop	Rate	Type	Syn. fert.	Crop
	Mg ha^{-1}		kg ha^{-1}		Mg ha^{-1}		kg ha^{-1}		Mg ha^{-1}		kg ha^{-1}	
Farm 1												
alt.‡	13.5	composted chicken§ manure	225 N 37 P	tomato	–¶	Sudangrass# c.c.††	– –	cotton	6.8	composted gin trash	84 N –	cotton
conv.‡		–	225 N 37 P	tomato		–	–	cotton		–	84 N –	cotton
Farm 2												
alt.	–	wheat c.c.	168 N 98 P	tomato		–	314 N –	garlic	–	wheat c.c.	135 N –	cotton
conv.		–	168 N 98 P	tomato		–	314 N –	garlic		–	135 N –	cotton
Farm 3												
alt.	11.2 +6.8	composted s.m.§§ s.m.	56 N –	tomato	6.8 +6.8	composted s.m. s.m.	56 N 22 P	garlic	6.8 +6.8	composted s.m. s.m.	– –	cotton
conv.		–	225 N –	tomato		–	168 N 56 P	garlic		–	90 N –	cotton
Farm 4												
alt.	13.5	composted chicken manure	202 N 49 P	tomato	–	barley¶¶ c.c.	243 N –	melon		–	101 N –	cotton
conv.		–	180 N 49 P	tomato		–	123 N –	cotton		–	101 N –	cotton
Farm 5												
alt.	22.5	composted gin trash	118 N 74 P	tomato	13.5 +	composted gin trash sudangrass c.c.	202 N 37 P	onion	13.5	composted gin trash and dairy manure	– –	cotton
conv.		–	118 N 74 P	tomato		–	202 N 37 P	onion		–	56 N –	cotton
Farm 6												
alt.	13.5	composted turkey## manure and s.m.	308 N 72 P	tomato	11.2 +–	composted s.m. sudangrass c.c.	240 N 49 P	tomato	–	sudangrass c.c.	191 N –	cotton
conv.		–	308 N 72 P	tomato		–	240 N 49 P	tomato		–	191 N –	cotton

† Syn. fert., synthetic fertilizer.
‡ alt., alternative treatment.
§ *Gallus gallus domesticus.*
¶ Rate not determined.
# *Sorghum × drummondii* (Steudel) Millsp. & Chase.
†† c.c., cover crop.
‡‡ conv., conventional treatment.
§§ s.m., steer manure.
¶¶ *Hordeum vulgare* L.
Meleagris gallopavo.

each. Treatment integrity was maintained over the entire 3-yr period on seven of the 11 farms. Only the results for these farms are presented here.

Participation and Design

Before the project was initiated, the project manager discussed management plans for the side-by-side conventional and alternative fields with each farmer individually and then with all participants as a group. The result of these negotiations was that cover crop, compost, or manure amendments would be used as supplements for alternative fields whenever possible. The conventional fields would not receive any C supplements (Table 1). The farmers were unwilling to accept the perceived risk of lost revenue associated with reducing synthetic fertilizer inputs on the alternative fields to reflect the nutrients in their chosen alternative treatment (SCMP). This required the alternative treatment to be viewed as a C supplement rather than a fertilizer replacement. All other management practices for each field pair were to be identical. It was impossible to develop full consensus among the farmers regarding what amendments to use or crops to grow. For this reason, we analyzed the results from each farm separately as well as across farms.

In one instance, the farmer participant (Farm 7) with extensive experience using organic systems preferred not to adhere to the comparison framework of alternative vs. conventional at all, choosing instead to compare compost with manure amendments (two alternatives without a conventional control). In 1997, we expanded sampling at Farm 7 to include adjacent fields under long-term management (Table 2). The short–term compost and manure-amended (3 yr each) fields were also compared with fields that were managed conventionally (for 10 yr or more), organically (10 yr without synthetic fertilizers or pesticides), and transitionally (2 yr organic management following long-term conventional practices). Project participants from NRCS Soil Survey created detailed soil maps for these fields to ensure that comparisons were valid. Soil types present in the fields were Cerini clay loam (Fluventic Haplocambids), Ciervo clay (Vertic Haplocambids), and Westhaven clay loam (Fluventic Haplocambids). The results from this comparison were analyzed apart from the primary study.

Table 2. Management treatments and crops grown at Farm 7 of the West Side On-Farm Demonstration Project (WSD) from 1996 through 1998.

	1996				1997				1998			
	Amendment				Amendment				Amendment			
System	Rate	Type	Syn. fert.†	Crop	Rate	Type	Syn. fert.	Crop	Rate	Type	Syn. fert.	Crop
	$Mg\ ha^{-1}$		$kg\ ha^{-1}$		$Mg\ ha^{-1}$		$kg\ ha^{-1}$		$Mg\ ha^{-1}$		$kg\ ha^{-1}$	
manure	11.2	poultry manure	– –	tomato	11.2	poultry manure	– –	melons	11.2	poultry manure	– –	tomato
compost	11.2	composted poultry manure	– –	tomato	11.2	composted poultry manure	– –	melons	11.2	composted poultry manure	– –	tomato
organic	11.2	poultry manure	– –	broccoli‡	11.2	poultry manure	– –	spinach§	11.2	poultry manure	– –	tomato
trans.¶		–	168 N –	cotton	11.2	poultry manure	202 N 72 P	tomato		–	326 N 127 P	garlic
conv.#		–	112 N 34 P	string bean††		–	168 N –	cotton		–	393 N 127 P	onion

† Syn. fert., synthetic fertilizer.
‡ *Brassica oleracea* L.
§ *Spinacia oleracea* L.
¶ trans., field in second year of transition from conventional to organic management.
\# conv., conventionally managed field (no organic amendments).
†† *Phaseolus vulgaris* L.

After completing sampling and analyses, we summarized and discussed the data with participating farmers to obtain their views and perceptions. These data summaries were subsequently presented and discussed with other farmers, advisors, and researchers.

Soil Sampling, Processing, and Analysis

Six composite soil samples were taken each spring and autumn from alternative and conventional fields. [For brevity, we report the results from the beginning and ending sampling dates (spring 1995 and fall 1998) only. Electrical conductivity (EC) was the only soil quality indicator that appeared to be affected by sampling time.] Each sample consisted of 8 to 12 bulked cores taken to a depth of 15 cm. The sampling protocol consisted of locating one of six fixed, central reference points using field measurements or global positioning system coordinates and then collecting soil cores in an X pattern within a 15-m radius of that point. In fields that were bedded before sampling, cores were collected from the furrow, shoulder, and center part of beds. In fields that had recently been disked or leveled, cores were collected randomly at each sampling site without regard to surface topography. Large pieces of raw organic material were removed from the soil surface before collecting the samples. After collection, the samples were refrigerated until passed through a (13- by 13-mm mesh size) sieve and then prepared for analysis.

Well-mixed, air-dried samples were analyzed for chemical and physical properties at the University of California's Division of Agriculture and Natural Resource Analytical Laboratory. Soil texture was determined for baseline soils in 1995 by the hydrometer method (Gee and Bauder, 1986). Soil bulk density (BD) was estimated by the core method (Blake and Hartge, 1986). Soil organic matter (SOM) was determined using the modified Walkley–Black method of Nelson and Sommers (1982). Total Kjeldahl nitrogen (TKN) was determined using the standard digestion of Issac and Johnson (1976). Soil NO_3–N was extracted with KCl (Keeney and Nelson, 1982). Extracts were analyzed for NO_3–N via Cd reduction by a modified Griess–Ilsovay method using a diffusion-conductivity analyzer (Carlson, 1978). Soluble P (Olsen P) was determined by sodium bicarbonate ($NaHCO_3$) extraction and subsequent colorimetric analysis (Olsen et al., 1954). Exchangeable K (x-K) (Knudson et al., 1982) and exchangeable Ca (Lanyon and Heald, 1982) were determined using an ammonium acetate extraction followed by emission spectrometry. Cation exchange capacity (CEC) was determined by the Ba saturation–Ca replacement method of Janitzky (1986). Zinc, Fe, and Mn were determined using the DTPA (diethylenetriaminepentaacetic acid) micronutrient extraction method developed by Lindsay and Norvell (1978). Sodium adsorption ratio (SAR) was calculated from saturated paste extracts of Na^+, Ca^{2+}, and Mg^{2+} in milliequivalents per liter (U.S. Salinity Lab. Staff, 1954). Electrical conductivity (Rhoades, 1982) and pH of water-saturated pastes (U.S. Salinity Lab. Staff, 1954) were measured using conductivity and pH meters, respectively. Soil aggregate stability was measured on 1- to 2-mm-diam. aggregates using the slow-wetting, wet-sieve procedure of Kemper and Rosenau (1986).

Soil biological properties were analyzed using field-moist samples from 1998. Potentially mineralizable N (PMN) was defined as NO_3–N that accumulated in 35-g (dry weight) soil samples during a 4-wk incubation at −30 kPa soil water potential before and after a 4-wk aerobic incubation (Bundy and Meisinger, 1994). For microbial biomass determinations, 20-g soil samples were used in the chloroform-incubation method described by Horwath et al. (1996). Microbial biomass N (MBN) was determined for these samples using a $K_n = 0.58$ conversion factor (Horwath and Paul, 1994).

Statistical Analyses

We compared the alternative and conventional treatment means for Farms 1 through 6 combined. The data for these farms are reported on a gravimetric basis because BD was determined only in 1998. We looked for differences between treatments on each sampling date and across the two dates using the nonparametric Wilcoxon rank sum (c^2) test on JMP v. 3 software for Windows (SAS Inst., Cary, NC).[1] This nonparametric test finds differences less often than its parametric counterpart, the *t*-test (Ott, 1988). Therefore, we believe the rank sum test may be more applicable than the *t*-test to on-farm studies, where scientific rigor and control over inputs are more difficult to obtain than in plot studies, because it is less likely to have false positive conclusions (Type I errors).

The expanded data set collected from Farm 7 in 1998,

[1] Reference to trade names and companies is made for information purposes only and does not imply endorsement by the USDA or University of California.

including five management systems (manure, compost, organic, transitional, and conventional), was evaluated for variables expressed volumetrically using a one-way analysis of variance (ANOVA) and Student's t comparison of means at $\alpha = 0.05$. We transformed data from this farm, as necessary, to meet statistical assumptions of normality and equal variances.

Soil Quality Index Demonstration

We constructed a SQI for the 1998 soils data from Farm 7, using techniques that performed well for a smaller-scale experiment of vegetable production systems in California's Central Valley (Karlen et al., 1999), to determine if the method was sufficiently robust for on-farm applications. Because innovative farmers routinely experiment with alternative management practices, often for only one season before making a decision to adopt, we evaluated a comparative assessment technique that does not have to be repeated as part of a time series. The three main steps of this technique are to (i) select a minimum data set (MDS) of indicators that best represent soil function, (ii) score the MDS indicators based on their performance of soil functions, and (iii) integrate the indicator scores into a comparative index of soil quality.

To select a representative MDS (Doran and Parkin, 1994) for the alternative systems, we first performed standardized principal component analysis (PCA) of all untransformed data that showed statistically significant differences between management systems using ANOVA or Student's t (as described above). Principal components (PCs) for a data set are defined as linear combinations of the variables that account for maximum variance within the set by describing vectors of closest fit to the n observations in p-dimensional space, subject to being orthogonal to one another. There are many documented strategies for using PCA or closely related factor analyses to select a subset from a large data set (e.g., Andrews and Carroll, 2001; Brejda et al., 2000). The strategy described here is similar to that described by Dunteman (1989). We assume that PCs receiving high values best represent system attributes. Therefore, we examined only the PCs with eigenvalues ≥ 1 (Brejda et al., 2000).

For a particular PC, each variable received a weight or factor loading that represents its contribution to the PC. We retained only the highly weighted variables from each PC for the MDS. We defined highly weighted as that within 10% of the highest factor loading (using absolute values). When more than one variable was retained within a PC, we calculated their linear correlations to determine whether the variables could be considered redundant and, therefore, eliminated from the MDS (Andrews, 1998). If the highly weighted variables were not correlated (assumed to be a correlation coefficient of <0.60), then each was considered important and was retained in the MDS. Among well-correlated variables within a PC, the variable with the highest sum of correlation coefficients (absolute values) was chosen for the MDS (Andrews and Carroll, 2001; Karlen et al., 1999).

As a check of how well the MDS represented the management system goals, we performed multiple regressions using the final MDS indicators as independent variables and measures representing management goals as dependent variables (Andrews and Carroll, 2001; Karlen et al., 1999). The available management goal variables were: yield (proportion of measured yield/county average to account for different crops), gross revenues (including price premiums for organic produce) (Fresno Dep. of Agric., 1998), and SAR (to represent sodicity concerns in this region).

After determining the MDS indicators, we scored each of the MDS variables based on their performance of soil functions using Stella Research v. 5.1.1 software (High Performance Syst., Hanover, NH). Every observation of the MDS indicators was transformed for all five treatments using nonlinear scoring functions where the y-axis ranged from 0 to 1 and the x-axis represented a site-dependent expected range (Andrews et al., 2001; Karlen et al., 1998; Karlen and Stott, 1994). A score of 1 was given when an indicator value represented high function, i.e., if the indicator was nonlimiting to related soil functions and processes such as nutrient cycling, water partitioning, supporting biodiversity, filtering and buffering, or structural stability. Scoring functions are used widely under various guises in economics as utility functions (Norgaard, 1994), multiobjective decision making as decision functions (Yakowitz et al., 1993), and systems engineering as a tool for modeling (Wymore, 1993). Andrews et al. (2001) found that nonlinear scoring of indicators was more representative of system function than linearly scored indicators over a large range of indicator values measured in northern California.

The expected range for the indicators (x-axis range) was determined based on observed values in this study and literature values for similar soils and climate (when available). The shape of the decision function—typically some variation of a normal distribution, an upper asymptote, or a lower asymptote—was determined by consensus of the researchers involved and literature values quantifying the relationships between indicators and soil functions (Fig. 1). For example, we used upper asymptotes or *more is better* functions for soil organic matter (SOM) and water-stable aggregates (WSA) based on their roles in soil fertility, water partitioning, and

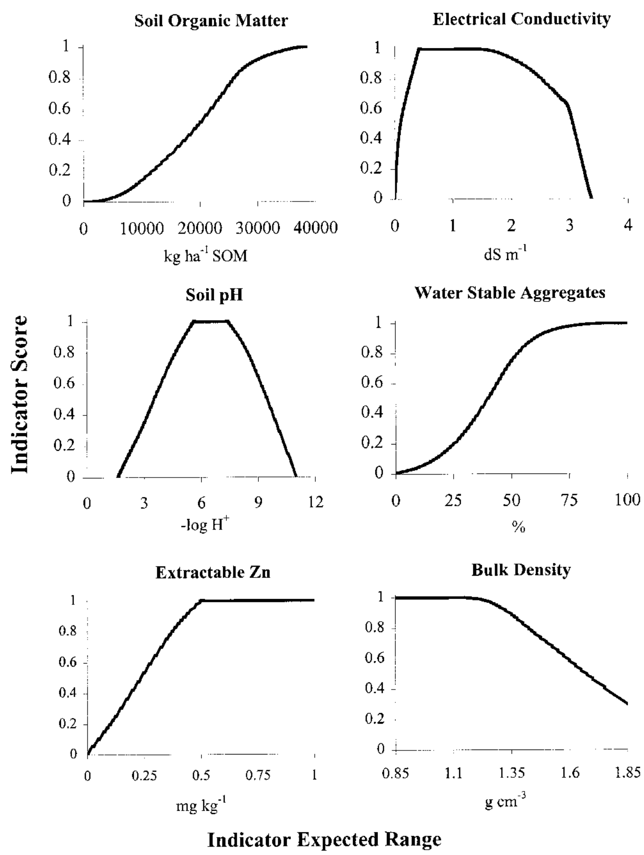

Fig. 1. The scoring functions used to transform the measured indicator values into performance-based scores for the soil quality index (SQI) where the *y*-axis represents soil quality value (or performance of soil function) and the *x*-axis is the site-dependent expected range for each indicator.

structural stability (Tiessen et al., 1994; Soil Survey Staff, 1998). We used a lower asymptote or *less is better* function for BD due to the inhibitory effect of high BD on root growth and soil porosity (Soil Survey Staff, 1998). Variations of midpoint optimum curves were used for soil pH (Whittaker, 1959), EC (Tanji, 1990), and Zn (Maynard, 1997) based on crop sensitivity levels and nutrient availability.

Once transformed, the MDS variables for each observation were weighted using the PCA results. Each PC explained a certain amount (%) of the variation in the total data set. This percentage, divided by the total percentage of variation explained by all PCs with eigenvectors >1, provided the weighting factor for variables chosen under a given PC. We then summed the weighted MDS variable scores for each observation in the following formula:

$$\mathrm{SQI} = \sum_{i=1}^{n} W_i \times S_i \qquad [1]$$

where W is the PC weighting factor and S is the indicator score. We compared the calculated SQI treatment means using ANOVA and Student's t at $\alpha = 0.10$. We assumed that higher index scores meant better soil quality or greater performance of soil functions.

RESULTS AND DISCUSSION

Participation

Despite numerous coordination efforts, SCMPs evaluated on participating farms varied considerably in type, amount, and chemical composition (Tables 1 and 2). Compost or manure was applied to alternative fields 14 times, late summer or winter cover crops were grown as green manure six times, and combinations of cover crops plus compost or manure were used twice during the project's 30-mo history (Hartz, 2000). Crop rotation among farms also differed. Such differences among experimental treatments would be intolerable in mechanistic research programs where control over experimental design is rarely in question. However, these on-farm studies were initiated to demonstrate that SOM building practices could be implemented in the SJV without interfering with current cropping practices and to provide preliminary soil test data that would help quantify the impact of those SOM building practices.

Interviews with farmer participants revealed that they were considering these soil amendments primarily as means of adding C to the soil to improve soil quality rather than as fertilizer replacements. Reluctance to reduce fertilizer application rates in alternative-treatment fields stemmed primarily from concerns about yield reductions. Farmers also emphasized that building soil fertility with organic materials generally takes longer than the 3-yr duration of this study. Their knowledge with respect to SOM and total organic C is supported by the scientific literature, e.g., Christensen (1996). However, their concept fails for plant-available N, P, K, and micronutrients; many studies have shown the short-term fertilizer effects of organic amendments, e.g., Yadvinder-Singh et al. (1992) for green manures, Stephenson et al. (1990) and Cabrera and Gordillo (1995) for animal wastes, and Gagnon and Simard (1999) for composts.

As information regarding changes in soil fertility became available for each alternative field, one WSD participant specifically requested guidelines from the management team about how he could refine his mineral fertilizer program for 1999. This attitudinal change is a very favorable outcome for a participatory project. Further, synthetic fertilizer reductions will be necessary to make organic amendments an environmentally safe option (Sims, 1995) for the SJV and other areas.

There are no data to quantify current annual use SCMPs in the West Side region of the SJV, but we estimate that they are not used on more than 5% of the row-crop land. In contrast, seven of the original 11 participating farmers (64%) maintained their on-farm comparisons between conventional and alternative soil management practices for the entire 3 yr.

There were several different reasons why the project's primary goal of utilizing SCMPs was not maintained on four of the original farms. In one case, financial considerations precluded purchase of the additional inputs. At two sites, a farm-wide decision was made to rotate the fields that received organic inputs; thus, the organic amendments were applied to other, nonproject fields in the second and/or third years. Finally, one farm was sold during the course of the project, and the new landowner was unable or unwilling to maintain the integrity of the side-by-side comparisons. The results from the remaining seven farms are presented below.

Soil Analyses on Farms 1 through 6

We report soil indicator results for samples taken when the project began in fall 1995 and in spring 1998 for the six farms that maintained consistent alternative and conventional treatments over the study period (Table 3). Several additional soil quality indicators were added during the course of the study and are reported for the ending date only (Table 4). Fourteen of 18 indicators exhibited significant differences between treatments, sampling dates, or both.

All indicators (except Mn) had significantly different baseline values between treatment fields at one or more farms. The number of significantly different indicators ranged from eight (of the 11 indicators sampled in 1995) at Farm 4 to one at Farm 6. Textural differences provide one explanation: Soil textures at Farms 1 through 5 varied slightly between adjacent fields but were mostly clays, clay loams, or loams. Soil textures for alternative and conventional fields at Farm 6 were classified as sandy loam or loamy sand (data not shown). Another suspected reason for baseline differences in 1995 was that sampling may have occurred after soil amendment treatments were applied to some farms. Exact dates of amendment applications with respect to soil sampling were not recorded. This is another example of the difficulties of working on farm where farmers' schedules do not always coincide with those of researchers. To deal with this potential bias, we performed statistical analyses on the percent difference between treatments for each indicator in each year, similar to the technique employed by Karlen and Colvin (1992) to compare farming

Table 3. Selected soil quality indicators sampled to a 15-cm depth at six San Joaquin Valley (SJV) farms in 1995 and 1998: soil organic matter (SOM); total Kjeldahl N (TKN); soil pH; electrical conductivity (EC); sodium adsorption ratio (SAR); cation exchange capacity (CEC); exchangeable K (x-K); water-stable aggregates (WSA); and extractable Fe, Mn, and Zn.

	SOM		TKN		pH		EC		SAR		CEC		x-K		WSA		Fe		Mn		Zn	
System	1995	1998†	1995	1998†	1995	1998†	1995	1998†	1995	1998†	1995	1998†	1995	1998†	1995	1998†	1995	1998†	1995	1998†	1995	1998†
	g kg^{-1}				−log H^{+}		dS m^{-1}				cmol kg^{-1}		mg kg^{-1}		%		g kg^{-1}					
Farm 1																						
Alt.‡	11.0	12.4*	0.81	0.74	7.8	7.7**	2.2	1.1**	3.2	2.5	32.9	31.4**	492	663**	88.8	89.4	11.4	11.0	19	17	1.5	3.4#
Conv.§	10.8	11.6**	0.72	0.64*	7.8	7.7*	2.7	1.2**	3.7	2.9**	34.6	33.3*	502	601**	91.1	89.0	10.2	8.4	18	11*	1.8	1.8
¶		*	*	*					*		#	*		*			*	*		#	*	#
Farm 2																						
Alt.	12.0	9.6#	0.86	0.73*	7.6	7.6	1.9	0.8#	1.5	1.5	31.8	31.5	504	475	86.7	91.0*	8.7	6.6*	18	13	3.3	1.8#
Conv.	10.8	7.3#	0.80	0.62#	7.7	7.8	1.3	0.5#	1.8	1.8	30.3	29.3*	446	384#	83.4	87.7	8.8	5.6#	13	9#	2.0	1.4#
¶	*	#		#	*	#	*	#		#		#	#	#		#		*		#	**	**
Farm 3																						
Alt.	10.7	11.1	0.81	1.29#	8.0	7.7#	1.0	1.5**	1.8	3.5#	31.8	30.7	523	579	84.2	88.0*	9.3	7.2*	18	12**	1.2	2.3*
Conv.	10.8	8.7#	0.82	1.02#	8.0	7.8#	1.3	1.3	2.2	3.5#	30.9	31.6	528	436#	84.9	90.6**	10.2	6.5**	20	11#	1.2	1.9*
¶		#		#		**	*	*						#		*						
Farm 4																						
Alt.	10.0	8.8**	0.82	0.75*	7.6	7.8	5.4	1.2#	4.3	2.1**	25.9	20.9#	477	442	73.4	79.8*	10.8	n.d.[n/a]††	17	n.d.[n/a]	1.4	n.d.[n/a]
Conv.	8.3	8.6	0.67	0.66	7.7	7.9#	1.6	0.8#	2.4	1.4#	21.8	18.0**	383	410	60.3	72.1#	15.3	n.d.[n/a]	21	n.d.[n/a]	1.0	n.d.[n/a]
¶	***		**			#	#		**	*	#		*		#	*	*				#	
Farm 5																						
Alt.	10.1	12.2*	0.70	0.79*	7.7	7.7	4.6	2.7#	6.9	5.5	33.3	31.8*	584	612	88.3	89.9	9.7	11.0	12	12	1.7	4.6#
Conv.	8.1	9.0#	0.61	0.61	7.7	7.7	2.6	1.8*	2.7	3.5*	29.5	28.7	414	462	88.0	87.5	12.9	6.8#	14	11#	1.7	3.2#
¶	#	#	*	#			#	*	#	*	#	#	#	#			*	**		#		*
Farm 6																						
Alt.	6.4	5.7	0.48	0.69#	7.9	7.8#	0.8	0.4#	1.3	0.8#	13.3	13.3	297	260	65.2	60.7	7.2	6.0*	11	10	1.8	2.7#
Conv.	6.3	3.5#	0.45	0.38	7.9	7.8	1.0	0.4#	1.5	0.8#	13.0	9.9#	277	169**	64.5	67.8	6.8	5.2	13	10*	1.8	1.5
¶		#		#					*			#		*		*		**				#
Means of Farms 1–6																						
Alt.	10.0	9.9	0.74	0.83	7.8	7.7*	2.6	1.5#	3.2	2.7	28.2	26.5	479	500	81.1	83.1*	9.5	8.3*	16	13**	1.9	2.9#
Conv.	9.2	8.0	0.68	0.70	7.8	7.8	1.7	1.0#	2.4	2.2	26.7	25.1	425	399	78.7	82.8	11.1	6.4#	16	11#	1.6	2.3**
¶	*	#	*	#		*							**	#			*	#		#		**

* Significant at the 0.05 level.
** Significant at the 0.01 level.
† Significance of χ^2 comparisons between years (1995 vs. 1998).
‡ Alt., alternative treatment using supplemental C management practices.
§ Conv., conventional treatment (no C supplement).
¶ Significance of χ^2 comparisons between management practices (alt. vs. conv.) within one year.
# Significant at the 0.005 level.
†† n.d., not determined; n/a, test not applicable.

systems. While the baseline differences are a concern, if sampling did occur after initial treatment applications, it would only serve to minimize treatment effects when analyzed over time, leading to more conservative conclusions.

Soil organic matter was higher in soils from alternative fields than from conventional fields at four of six farms in 1998 (Table 3). Similarly, TKN was significantly higher in soils from alternative fields than in soils from conventional fields in five of six farms. However, several farms also had significant treatment differences in 1995, including Farm 5 where we suspect treatments were applied before collection of baseline samples. The alternative field soils had an average of 8% more SOM and TKN than conventionally managed soils in 1995 but 16% more SOM and 19% more TKN in 1998 ($P > 0.001$ for each). These on-farm changes in SOM are consistent with those reported by Clark et al. (1998) for both organic and low-input cropping systems in California's Sacramento Valley.

Although differences between treatments within each year were significant, the temporal changes in SOM and TKN were less consistent: Some farms showed increases while others showed decreases or no change in these indicators. One likely reason for these inconsistent temporal responses is the differing quality of the amendments used at the six farms (i.e., differences in C/N or lignin/N ratio of the amendment itself).

Another factor in the SOM and TKN responses may be the high number and intensity of tillage operations performed in both alternative and conventional treatments. Tillage has long been known to deplete SOM (Reicosky et al., 1995). A written survey including eight participating farmers conducted during a routine progress report meeting revealed that an average of more than six tillage operations are performed each year (S.S. Andrews, J.P. Mitchell, and D.L. Karlen, unpublished data, 1999). Evidence for a tillage effect is found in the downward trend in mean soil C/N ratio {calculated as [(SOM × 0.8)/TKN]} for all fields on Farms 1 through 6. The ratio was significantly lower in 1998 (9.9:1) than in 1995 (10.8:1) ($P < 0.009$). Mean soil C/N ratio from alternative and conventional fields followed this trend separately but with less statistical significance ($P < 0.08$ for alternative and $P < 0.05$ for conventional). Conversely, the mean percentage of WSA increased over

Table 4. Selected soil characteristics from soils (0- to 15-cm depth) at six San Joaquin Valley (SJV) farms in 1998 only: bulk density (BD), exchangeable Ca (x-Ca), Olsen P (P), potentially mineralizable N (PMN), microbial biomass C (MBC), and microbial biomass N (MBN).

System	BD	x-Ca	P	NO_3–N	PMN	MBC	MBN
	g cm^{-3}	mg kg^{-1}					
Farm 1							
Alt.†	1.32	1802	45	42.5	9.1	374	52
Conv.‡	1.26	1734	27	33.9	3.7	318	40
§			*	*	**	*	*
Farm 2							
Alt.	1.50	2558	15	22.6	12.6	341	72
Conv.	1.28	2568	12	10.6	4.8	152	27
§	*			¶		¶	¶
Farm 3							
Alt.	1.22	2343	47	19.6	11.7	314	63
Conv.	1.36	2610	33	14.7	6.3	188	38
§	¶	*	*	*		¶	¶
Farm 4							
Alt.	1.04	2492	18	19.9	8.4	136	33
Conv.	1.28	2362	18	10.7	6.4	161	36
§		*		**			
Farm 5							
Alt.	1.22	2497	55	40.8	17.6	232	46
Conv.	1.25	2072	23	35.7	11.7	229	42
§			¶				
Farm 6							
Alt.	1.31	995	29	5.7	8.4	138	26
Conv.	1.38	765	23	3.4	6.2	103	17
§	*	¶	*	*		*	**
Means of Farms 1–6							
Alt.	1.27	2123	34	24.7	11.0	256	49
Conv.	1.30	2027	23	17.7	6.6	192	33
§			**	*	¶	**	¶

* Significant at the 0.05 level.
** Significant at the 0.01 level.
† Alt., alternative treatment using supplemental C management practices.
‡ Conv., conventional treatment (no C supplement).
§ Significance of χ^2 comparisons between management practices.
¶ Significant at the 0.005 level.

time at Farms 1 through 6 in the alternative fields, a change that was attributed to increases at three farms. This is a positive statement for the ability of SOM amendments to increase soil stability despite intensive annual tillage disturbance.

Soil pH was significantly lower in 1998 compared with 1995 for alternative fields on three of six farms and for the combined-farm treatment means (Table 3). This same trend was observed for the conventional fields at three farms (but not for the combined-farm treatment means). Electrical conductivity also decreased significantly over time for both treatments (Table 3). Seasonal differences probably contributed to this result because winter rains have been shown to decrease springtime EC (Weinhold and Trooien, 1995). Sodium adsorption ratio and CEC showed no consistent trends between treatments or over time and did not appear to be sensitive soil quality indicators for these systems. Exchangeable K was significantly higher on alternative fields compared with conventional fields in five of six farms and the treatment means in 1998. While there were also significant treatment differences in 1995, the x-K mean for the alternative treatment was 11% greater than the conventional treatment in 1995 and 20% greater in 1998 ($P > 0.007$). This was expected because K is a significant component of many organic amendments (Stephenson et al., 1990) although amounts in the current study were not quantified. Increased x-K is also consistent with the greater number of exchange sites associated with increased organic matter levels (Duxbury et al., 1989).

Extractable Fe, Mn, and Zn were significantly higher in soils from alternative fields compared with those from conventional fields in 1998 (Table 3). Both treatments had increased Zn while Fe and Mn concentrations decreased in both alternative and conventional treatments over time. The temporal trends in soil micronutrients warrant further investigation.

We analyzed seven soil quality indicators in 1998 that were not tested in 1995 (Table 4). Of these, only BD and exchangeable Ca showed no consistent trends between treatments across farms. Four of the six alternative fields (and the treatment mean) tested significantly higher in Olsen P compared with conventional fields. The alternative treatment that included only cover crops (no manures or composts) was one of the two that did not show differences in Olsen P. This is consistent with previously reported high levels of P in manure-amended soils (Sharpley et al., 1994). Soil NO_3–N was significantly higher at five of six alternative fields. This is in agreement with the findings of Sharpley et al. (1993), who found higher levels of NO_3–N and NH_4–N among organic waste–amended clayey, fine-silty, and fine-loamy soils compared with unamended control soils. Mean PMN was significantly higher in soils from alternative fields compared with soils from conventional fields. However, PMN results from the individual farms showed significant differences in PMN only on Farm 1. In 1998, microbial biomass C and N were both significantly higher in the alternative fields at four of six sites and in treatment means. Biomass C and N were on average 25 and 32% higher, respectively, in soils from alternative fields than in soils from conventionally managed fields. This finding is consistent with studies using various organic amendments on different soils (e.g., Bolton, 1985; Kirchner et al., 1993; Perucci, 1992).

The on-farm comparisons of alternative and conventional practices (Tables 3 and 4) provided an indication of the short-term impacts of SOM management practices in this region. Potential long-term impacts of those practices can be envisioned from the comparisons at Farm 7 (Table 5). At this site, we compared fields that received short-term compost and manure amendments, conventional management, long-term organic management, and transitional management from conventional to organic practices. Sixteen out of 18 soil properties differed significantly among treatments. Soil-exchangeable Ca was the only measurement that did not show significant differences among the five management systems. Soil pH showed no significant differences by ANOVA, but Student's *t* showed the conventional system to have a significantly higher pH than the manure system at $\alpha = 0.05$.

Similar to the six-farm comparison, SOM and TKN were significantly higher in the organically managed and compost-amended soils than in the conventional and transitional soils at Farm 7 (Table 5). Water-stable aggregates, CEC, and x-K were higher for the organic

Table 5. Organic matter treatment effects on selected soil quality indicators to a depth of 15 cm at Farm 7 in 1998: soil organic matter (SOM); total Kjeldahl N (TKN); bulk density (BD); soil pH; electrical conductivity (EC); sodium adsorption ratio (SAR); cation exchange capacity (CEC); water-stable aggregates (WSA); exchangeable Ca (x-Ca); exchangeable K (x-K); extractable Fe, Mn, and Zn; Olsen P (P); potentially mineralizable N (PMN); microbial biomass C (MBC); and microbial biomass N (MBN).

System	SOM	TKN	BD	pH	EC	SAR	CEC	WSA	x-Ca	x-K	Fe	Mn	Zn	P	NO_3–N	PMN	MBC	MB
	— Mg ha^{-1} —		g cm^{-3}	−log H^+	dS m^{-1}		cmol kg^{-1}	%	Mg ha^{-1}	kg ha^{-1}								
Manure	19.2^{b}*	2.4^{b}	1.29^{a}†	7.3^{b}	1.6^{a}	2.2^{ab}	27.8^{bc}	87.5^{ab}	2.89	19.5	16.1^{a}	43^{a}	5.5^{b}	124	96^{a}	37.6^{ab}	671^{a}	117^{b}
Compost	20.6^{b}	2.6^{ab}	1.30^{a}	7.5^{ab}	1.7^{a}	2.4^{a}	29.3^{ab}	86.1^{b}	3.05	17.8	17.7^{a}	32^{b}	7.2^{a}	112	126^{a}	24.7^{b}	427^{bc}	76^{c}
Organic	24.5^{a}	2.7^{a}	1.20^{b}	7.4^{ab}	1.8^{a}	2.0^{b}	32.3^{a}	94.0^{a}	3.55	27.2	16.7^{a}	51^{a}	7.4^{a}	142	142^{a}	60.9^{a}	795^{a}	164^{a}
Transitional	16.6^{c}	2.1^{c}	1.34^{a}	7.5^{ab}	0.6^{b}	1.3^{c}	24.6^{c}	81.2^{b}	3.22	6.5	13.4^{b}	32^{b}	8.0^{a}	49	28^{b}	12.8^{b}	492^{b}	78^{c}
Conventional	14.9^{c}	1.9^{d}	1.28^{ab}	7.6^{a}	0.7^{b}	1.4^{c}	26.2^{bc}	84.5^{b}	3.08	6.5	10.7^{c}	24^{b}	8.4^{a}	59	33^{b}	11.7^{b}	353^{c}	71^{c}
$P <$ †	0.0001	0.0001	0.037	0.131	0.0001	0.0001	0.001	0.007	0.665	0.000	0.0001	0.0001	0.016	0.0001	0.0001	0.014	0.0001	0.0001

* Treatment means followed by different letters are significantly different at $\alpha = 0.05$.
† Significance of ANOVA comparisons between management practices.

system than for the conventional or transitional systems. Also, WSA, CEC, and x-K were higher for the organic system than for the compost system, manure system, or both, respectively. Soil BD was significantly lower in the long-term organic field compared with all other systems except the conventional. In other studies, organic matter has been linked to decreased soil BD (Weil and Kroontje, 1979), increased WSA (Tisdale and Oades, 1982), and increased CEC (Duxbury et al., 1989).

Several of the extractable nutrients (Olsen P, extractable Fe, and NO_3–N) were higher in manure amended, compost amended, and organically managed soils compared with conventional and transitional soils. Extractable Mn was higher in the organic and manure systems only. Results for Zn seem to conflict with results for other micronutrients; the only difference between systems was a reduced mean Zn concentration in the manure system.

Many of these results are consistent with findings from the Sustainable Agriculture Farming Systems (SAFS) Project, a long-term, plot-scale cropping system experiment in California's Central Valley. At the SAFS site, SOM, Olsen P, and x-K were all significantly higher in the cover crop–based, low-input system or compost- and cover crop–based organic system compared with the conventional systems (Clark et al., 1998).

In the compost, manure, and long-term organic systems, EC and SAR were significantly higher than in the transitional and conventional systems (Table 5). This may be due to increased imports of Na relative to Ca in the organic amendments, which might eventually lead to problems with the organic treatments under irrigation, such as reduced water infiltration and salt toxicity to plants. However, observed levels are well below sodic or saline threshold levels, even for sensitive crops. This result is in direct conflict with results of Clark et al. (1998), who found organic and low-input systems based on cover crops and manures to have significantly lower EC than conventional systems. Electrical conductivity in the 10-yr organic treatment at Farm 7 was not significantly greater than that of the 3-yr compost and manure treatments, suggesting that EC and SAR increased in the first few years and then stabilized, perhaps as a result of SOM buildup and associated binding of multivalent cations as bridges between humic and mineral phases (Stephenson, 1994).

In contrast to Farms 1 though 6, PMN at Farm 7 appears to be as sensitive to differences between systems as microbial biomass C and MBN (Table 5). Potentially mineralizable N, microbial biomass C, and MBN were significantly higher in the organic system than in the compost, transitional, and conventional systems. Potentially mineralizable N in the manure system was not different from the other systems. Microbial biomass C in the manure system was not significantly different from that found in the organic system. The manure system was significantly lower in MBN than the organic system but higher than the other three systems.

Soil Quality Index Demonstration

Because many measurements of potential soil quality indicators were examined for the first time in these SJV soils, the information gained from Farm 7 provided an exceptional opportunity to demonstrate an approach recently evaluated for vegetable production systems (0.12-ha plots) in California's Central Valley (Karlen et al., 1999). Previously, this approach to select a unique, site-specific MDS had only been used in humid regions (Andrews, 1998; Karlen et al., 1998). We opted to compute the index for Farm 7 because of the greater number of data points available, which Andrews et al. (2001) found beneficial to the accuracy of statistical indicator selection. The trade-off was that no baseline data was available for the long-term organic, conventional, and transitional fields. We reasoned that the choice to include these fields was justified due to the similarity of soil series found in the fields, as mapped especially for this project by NRCS collaborators.

In the PCA of indicators that showed significant differences between management systems at Farm 7 in 1998, four PCs had eigenvalues >1 (Table 6). Highly weighted variables under PC1 included SOM, TKN, EC, x-K, Olsen P, and MBN. Correlation coefficients between these variables revealed EC to be uncorrelated with the other highly weighted variables. Hence, EC was retained for the MDS. Of the remaining five well-correlated variables, SOM was the most highly correlated and was chosen for the MDS as the most representative of that group. Under PC2, pH and WSA were highly weighted but not correlated. Both were retained for the MDS. Only one indicator each was highly weighted under PC3 (Zn) and PC4 (BD). Both variables were added to the MDS. The final MDS was thus comprised of SOM, EC, pH, WSA, Zn, and BD. This MDS is very similar to the PCA-chosen MDS in the SAFS experiment, which included SOM, EC, pH, TKN, and

Table 6. Results of principal component analysis (PCA) of selected soil quality indicators from the five management systems at West Side Demonstration (WSD) Farm 7 in 1998.

PCs†	PC1	PC2	PC3	PC4	PC5
Eigenvalue:	*8.60*‡	*2.22*	*1.93*	*1.24*	0.80
Percent:	50.60	13.06	11.35	7.30	4.70
Cumulative percent:	50.60	63.67	75.02	82.32	87.01
Eigenvectors:§					
SOM, kg ha^{-1}	*0.295*¶	−0.033	0.265	0.134	−0.187
TKN, kg ha^{-1}	*0.288*#	−0.133	0.154	0.322	−0.095
BD, g cm^{-3}	−0.127	−0.315	0.209	*0.563*	0.302
pH, −log H$^+$	−0.104	*0.522*	0.094	0.253	0.119
EC, dS m^{-1}	*0.282*	−0.085	−0.280	−0.013	0.287
SAR	0.222	−0.102	−0.351	0.373	0.227
CEC, cmol kg^{-1}	0.216	0.452	−0.004	0.164	−0.205
WSA, %	0.197	*0.486*	0.008	0.079	0.130
x-K, kg ha^{-1}	*0.303*	−0.010	0.260	0.046	−0.123
Fe, kg ha^{-1}	0.238	−0.147	−0.208	0.250	−0.554
Mn, kg ha^{-1}	*0.277*	−0.191	0.009	−0.362	−0.086
Zn, kg ha^{-1}	−0.093	−0.254	*0.441*	−0.025	−0.002
Olsen P, kg ha^{-1}	*0.288*	−0.119	−0.080	0.115	0.081
NO_3–N, kg ha^{-1}	0.245	−0.048	−0.334	−0.220	−0.013
PMN, kg ha^{-1}	0.265	−0.024	0.019	−0.132	0.553
MBC, kg ha^{-1}	0.256	0.028	0.331	−0.146	0.053
MBN, kg ha^{-1}	*0.275*	0.103	0.344	−0.171	0.118

† PC, principal component.
‡ Eigenvalues in italic correspond to the PCs examined for the index.
§ SOM, soil organic matter; TKN, total Kjeldahl N; BD, bulk density; EC, electrical conductivity; SAR, sodium adsorption ratio; CEC, cation exchange capacity; WSA, water-stable aggregates; x-K, exchangeable K; PMN, potentially mineralizable N; MBC, microbial biomass C; MBN, microbial biomass N.
¶ Underlined factor loadings correspond to the indicators included in the MDS.
# Factor loadings in italic are considered highly weighted.

exchangeable Mg and Ca (Karlen et al., 1999). We suggest that this similar composition of MDS's is important, considering there were differences in soil type, scale, inputs, and analyses performed for the two studies.

Table 7. Variables used as measures of management goals to test the efficacy of the minimum data set (MDS) at Farm 7: gross revenues (REV), yield as a proportion of county average (YLD), and sodium adsorption ration (SAR).

System	REV†	YLD†	SAR
	\$ ha^{-1}		
Manure	2295	0.86	2.2^{a}*
Compost	2648	0.99	2.4^{ab}
Organic	2380	0.89	2.0^{b}
Transitional	1807	1.11	1.3^{c}
Conventional	1564	1.08	1.4^{c}
P < ‡	0.0001	0.0001	0.0001

* Treatment means followed by different letters are significantly different at = 0.05.
† Means comparison tests are not applicable because values are single observances for each treatment.
‡ Significance of nonparametric χ^2 comparisons between management practices.

We used management goal data (Table 7) in a validation check of the MDS representation of the system. Multiple regressions of the MDS indicators as independent variables and management goal data as iterative dependent variables yielded coefficients of determination (r^2) of 0.81 for proportional yield, 0.84 for gross revenues, and 0.77 for SAR. This suggests that the MDS is responsive to several management goals in this system. In a more controlled environment (i.e., plot studies vs. on-farm trials), we would also include regressions against measures of environmental goals such as erosion and leaching. Nevertheless, these results are consistent with results from this technique in northern California (Karlen et al., 1999) and in Georgia (Andrews, 1998; Andrews and Carroll, 2001) where greater numbers of management goal variables were measured.

After the indicators were transformed using scoring

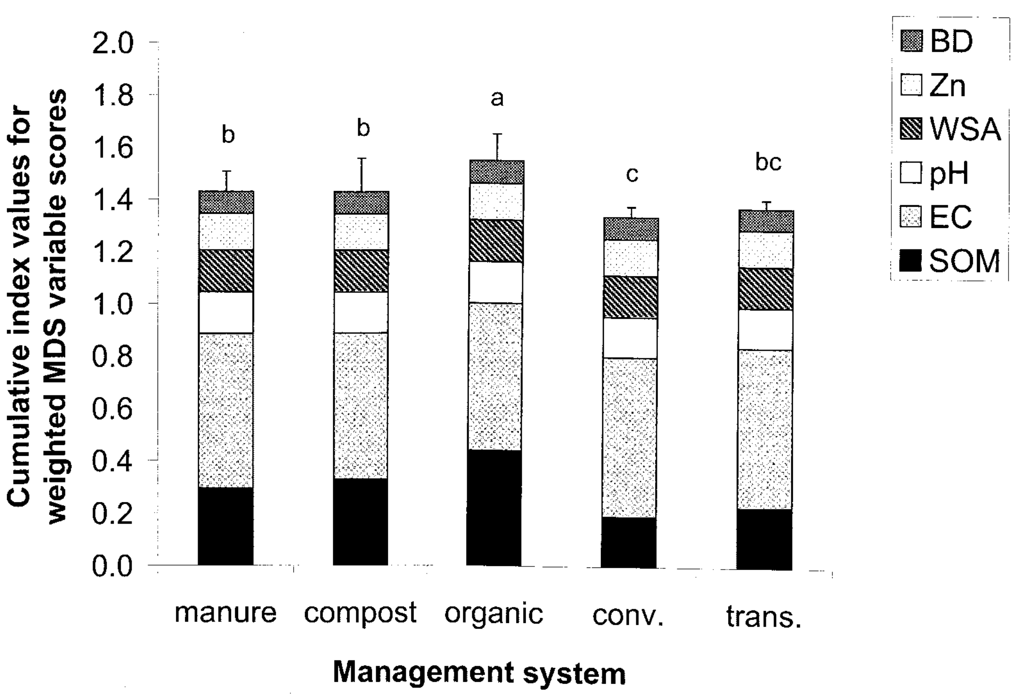

Fig. 2. Soil quality index (SQI) results for management comparisons at Farm 7 in 1998. Stacked bars show the component (scored and weighted) indicator means added to derive the overall index values. Error bars denote standard deviation of overall index values. Significant differences between treatments are denoted by different letters at α = 0.10. BD, bulk density; WSA, water-stable aggregates; EC, electrical conductivity; SOM, soil organic matter.

functions (as shown in Fig. 1), the SQI was calculated using weighting factors for each scored MDS variable according to the following formula:

$$\mathrm{SQI} = \sum_{i=1}^{n} 0.61 \times S_{\mathrm{SOMi}} + 0.61 \times S_{\mathrm{ECi}} + 0.16 \times S_{\mathrm{pHi}} + 0.16 \times S_{\mathrm{WSAi}} + 0.14 \times S_{\mathrm{Zni}} + 0.09 \times S_{\mathrm{BDi}} \qquad [2]$$

where S is the score for the subscripted variable and the coefficients are the weighting factors derived from the PCA. Weights were determined by the percent of variation in the data set explained by the PC that contributed the indicated variable divided by the total percentage of variation explained by all PCs with eigenvectors > 1 (see Table 6). Using this formula, the SOM and EC variables appear to drive the SQI results (Fig. 2). The organic system received the highest SQI value. Soil quality indices for the manure and compost systems were significantly lower than the organic system but significantly higher than the conventional treatment. The SQI value of the transitional system was not significantly different from the manure, compost, or conventional systems. These results are supported by the SQI outcomes from the SAFS experiment where the organic and low-input plots consistently received higher SQI scores compared with the conventional treatments (Karlen et al., 1999).

When these results were presented to the participating farmers, they expressed interest in the integrative index, especially if used over time (data not shown). However, they preferred to have indicators scored on a scale of 0 to 10 or 100, rather that 0 to 1, to allow for more apparent differences among treatment fields. This would be simple to do and makes sense given that in practice, farmers would have few replicates available to draw statistically valid conclusions. The index outcomes may reflect better yield to the extent that they reflect soil functions such as nutrient cycling and water partitioning. These outcomes may also reflect ecosystem services such as filtering and buffering for environmental protection. It is likely that these benefits would be most apparent under stress conditions, i.e., severe drought or heat, when soil function is less able to be subsidized by additional inputs (Herrick et al., 2002).

SUMMARY AND CONCLUSIONS

Negotiating the on-farm participatory research design was a learning process for all involved and from the extension–outreach perspective, very successful. The participatory nature of this project made the results accessible and useful to the farmers involved. Although there was reluctance among WSD participants to reduce mineral fertilizer inputs in their alternative fields, all participants agreed that the information exchange facilitated by this project may make such reductions more feasible in the future. Despite variations in SCMPs among farms, a number of soil quality indicators varied significantly. Some of the most significant changes were for SOM, TKN, x-K, and MBN, all of which were highly correlated. These data provide clear evidence that indicator properties can be changed through SOM building practices in an irrigated, mediterranean climate such as that of the SJV. The fact that these differences were measurable in an on-farm experiment utilizing the intensive tillage practices typical in the SJV (Mitchell et al., 2001) suggests simple SCMPs could significantly improve soil function without necessitating major management system changes in this region. However, reductions in synthetic fertilizer inputs commensurate with the fertilizer effect of the organic input will be necessary to reduce environmental risk (Sims, 1995).

This study also demonstrated that techniques used to compute SQIs for controlled experiments could be successfully applied to on-farm studies in the SJV by selecting site-specific indicators for a MDS, scoring indicators according to their performance of soil functions, and combining the scored values into an integrative index. This framework emphasizes that soil quality assessment is a tool that can be used to evaluate the effects of land management practices on soil function.

ACKNOWLEDGMENTS

This research was funded in part by the Kearney Foundation of Soil Science and the USDA-NRCS Soil Quality Institute. The authors wish to thank M.M. Wander and M.A. Liebig for useful commentary on the manuscript.

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Soil Quality: Science and Process

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ABSTRACT

The term soil quality (SQ) encompasses both a soil's productive and environmental capabilities. Strategies or frameworks that help farmers manage SQ are vital as sole emphasis on production can have negative environmental consequences and exclusive focus on environmental considerations could endanger supplies of food or fiber. Recent efforts in the USA have prioritized the development of SQ assessment strategies that would be used by individual farmers. The Illinois Soil Quality Initiative (ISQI) is an example of a participatory research strategy coupled with a SQ index-screening trial conducted on farm fields. A multivariate approach was used to identify promising indices and document tradeoffs in soil condition that were associated with tillage choices. Participatory aspects of the project confirmed that farmers appreciated the multivariate nature of soil and had great interest in SQ and stewardship. A dialogue component of the project had been structured to identify and then respond to cooperators' SQ information needs and to contribute to the development of indices that were related to soil function. Cooperator feedback suggested that a simple extension of this approach would be incapable of motivating or justifying the adoption of SQ building practices because factors constraining management choices were primarily structural (socioeconomic). Constructive follow-up efforts might strive to develop techniques to integrate SQ information into frameworks that reflect the outcomes to be achieved within social or economic contexts. Only by devising such strategies (which might combine models, indices, expert knowledge, and/or direct measurement) will we be able to manage the soil resource to achieve desired ends.

Since its inception, the soil quality (SQ) concept has been strongly associated with efforts to address agricultural sustainability (Youngberg, 1992; Parr et al., 1992; Warkentin, 1995). General definitions for SQ, which are understandably broad, emphasize the capacity of soil to perform services including the production of plants and animals and the transport and regulation of matter (water and other compounds) present in or added to soils (Doran and Parkin, 1994; Karlen et al., 1998). In addition, descriptions of SQ reflect appreciation for soils' fitness for use (Larson and Pierce, 1994) and the capacity of soil to resist and recover from degradation (Blum, 1998; Greenland and Szabolcs, 1994). Inherent differences in soils arise from influences of various climates, parent materials, topographies, and biota, all acting over geologic time (Jenny, 1941). Inherent differences are well reflected by the soil series description of the U.S. system of soil taxonomy, which includes a relatively complete description of the makeup and characteristics of the horizons present in a given soil. A variety of classification systems have been developed to describe the soils' suitability for specific types of land use and natural ability to tolerate factors that degrade soils; these inherent characteristics of soils vary within and among continents (Fig. 1), regions, and landscapes (Eswaran et al., 1999; Oldeman et al., 1991). The traits that provide the basis for taxonomic classification schemes are relatively use-invariant and so are not as useful as are dynamic aspects of soils that change as a function of human management expressed over a comparatively short time frame (within a decade) (Lal, 1998). Dynamic fractions of organic matter (Gregorich et al., 1994) or biological and physical aspects of soils influenced by organic matter status that are responsive to management are often favored as indices of SQ (Wander and Bollero, 1999; Wander and Drinkwater, 2000). This is true even in environments where concentrations of soil organic matter are quite low (Bird et al., 2000).

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Published in Agron. J. 94:23–32 (2002).

Midwest Row Crop Systems

A balance between the productive and environmental performance of Midwest soils must be sought as pressure on these lands is likely to increase. Many argue that there is a need to maintain or even increase the production capacity of land to satisfy growing food and fiber demands and spare land for alternate uses (World Resources Inst., 1998; Waggoner, 1994). Increasing demand for high quality water will likely reduce agricultural access to irrigation waters (FAO, 1997; World Meteorol. Organ., 1997), making stewardship of soils used for rainfed production all the more important. Increases in monoculture production of cash grains, cultivation, and reliance on chemical fertilizers and pesticides have increased yields and reduced on-farm labor demands; however, these intensified production practices are often associated with losses in soil organic matter, increased erosion, and surface and ground water contam-

Abbreviations: CT, conventional tillage; ISQI, Illinois Soil Quality Initiative; ND, nondisturbed; NT, no-till; POM, particulate organic matter; SQ, soil quality.